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Comprehensive characterization of Brazilian extra virgin olive oils by identity, quality, and tocopherols analysis: An evaluation between regions, crops, and cultivars

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ABSTRACT

Olive oil production is recent in Brazil and started in two distinct regions, Rio Grande do Sul State (RS) and Serra da Mantiqueira (MA). Many cultivars are being evaluated for productivity and disease resistance. Assessing olive oil quality and purity characteristics is relevant for consumer protection and to comply with national regulations. A total of 104 samples were evaluated for quality parameters (acidity, UV absorbance, peroxide value), fatty acids and tocopherol profiles. All samples met the legal parameters for extra virgin olive oils with slight differences for the fatty acids. Significant differences ($p < 0.05$) were observed for most of the data according to regions and cultivars. The main markers for discrimination were fatty acids and α-tocopherol. The C18:1 content was higher for MA region (77 vs 72%) while total tocopherols were higher for RS region (315 vs 242 mg/kg). Application of statistical tools made possible to differentiate the samples according to origin (RS and MA) and the discrimination of Arbequina from Koroneiki cultivars, independent of their geographical origin and which is useful for claims of geographical indication.

1. Introduction

Brazil is the world's second largest importer of olive oil, with 81,000 tons for the 2023/2024 crop (International Olive Council, 2026). Brazilian olive oil production is quite recent and small, corresponding to less than 1% of the imported oil (Embrapa, 2023). Notwithstanding, Brazilian olive oils are collecting many international quality prizes and Brazil has just entered the top 5 list of most awarded countries regarding olive oil quality (Salati, 2024).

Different from other producer countries, such as Italy, Spain, and Greece, Brazil has only two important production regions of olive oil, one in the lowlands of the state of Rio Grande do Sul (RS) in the south of the country, and the other in the Serra da Mantiqueira (MA), which is located between the states of Minas Gerais, Rio de Janeiro and São Paulo (Embrapa, 2023). Rio Grande do Sul state has the largest planted area, with around 4500 ha (Filoda et al., 2021).

The cultivars grown in Brazil include Arbequina, Arbosana, Coratina, Frantoio, Grappolo, Koroneiki, Manzanilla, and Picual. Arbequina and Koroneiki are the most cultivated ones, as they have adapted well to the climate and soil of the producing regions (Filoda et al., 2021).

Olive oil composition and quality depend on the genotype, environmental, agronomic, and technological factors, as well as fruit ripening, harvesting and storage conditions (Inglese et al., 2010). They are directly linked to the climate of the region where the olive trees are grown, as this influences pollination, flowering, and the ripening time of the fruits (Kalogeropoulos and Kaliora, 2015; Malheiro et al., 2015).

Differences in fatty acid composition, volatiles, phenolics, and tocopherols have been reported in the literature regarding in olive oils produced in distinct regions (Brilhante, 2024; Brilhante et al., 2024, 2022; Crizel et al., 2020; Garavaglia et al., 2023) and countries (Stilo et al., 2023) or from different cultivars (Ballus et al., 2014; Brilhante et al., 2024; Carvalho et al., 2021; Lima et al., 2023; Rodrigues et al., 2019). While olive oil production in Europe takes place in the semi-arid regions of the Mediterranean, in Brazil, a country with a tropical climate, production is concentrated in areas with greater annual rainfall and higher minimum temperatures. This has been a challenge for producers (Wrege et al., 2015a, 2015b).

On the other hand, these edaphoclimatic and genotypic differences

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impart variations in the metabolism of the olive tree and, consequently, in the chemical composition of the olive oils. These differences are desired, as they result in products with peculiar sensory characteristics that attract new markets and consumers. Moreover, they can be applied to discriminate oils according to their production areas, supporting geographical indication claims, such as protected designation of origin, which require experimental evidence to link the geographical area to specific chemical and sensorial attributes (European Commission, 2025).

There is a consensus that olive oil consumption has a positive effect on human health, and evidence of this has been gathered, especially in the prevention of chronic non-communicable diseases such as cardiovascular diseases, breast cancer, and type 2 diabetes mellitus (Foscolou et al., 2018). These benefits are attributed to the presence of its bioactive components including monounsaturated, polyunsaturated fatty acids, tocopherols, and polyphenols (Nocella et al., 2018). Phenolics and tocopherols exhibit antioxidant activity, and a synergistic effect of these compounds in relation to the antioxidant properties of olive oil is also known. Furthermore, tocopherols exhibit activity as vitamin E (Pérez et al., 2019).

Considering the continuous increase in demand and the high production cost of virgin olive oil, when compared to other oils, it is necessary to control its quality and composition, as cases of substitution or adulteration with lower-cost products do not simply constitute fraud, but can also have implications for the health of consumers (Boskou et al., 2006). It is also important to highlight that edible oils are one of the most adulterated foods in the world, and olive oil is no exception. In 2019 the Annual Report of the European Union Food Fraud Network showed the "Fats and oils" category as the one that recorded the highest number of requests, with olive oil being the most frequently reported within the system. It is estimated that between 75% and 80% of extra virgin olive oils (EVOOs) sold in the United States are adulterated, and that EVOOs fraud in Italy is an industry worth around 16 billion euros (García-González et al., 2010; Sudhakar et al., 2021). Furthermore, for olive oil producers, understanding and controlling the quality standards allow them to take coherent decisions about conditions and processing procedures according to the level of quality they want to achieve (Mariotti and Peri, 2014).

The evaluation of EVOO composition, quality, sensory attributes is essential to guarantee authenticity, traceability, and compliance with standards and regulations. In this context, quality analyses are useful for measuring hydrolytic and oxidative degradation in olive oils, and identity analysis aims to verify whether the product is authentic. For olive oils, quality standards can be divided into two groups, chemical and sensory (Mariotti and Peri, 2014). The Brazilian legislation is harmonized with the Codex Alimentarius and classifies olive oil according to the quality parameters of free fatty acid, peroxide value, specific ultraviolet extinction, and sensory characteristics, as virgin, extra virgin, or lampante/ordinary (Brasil, 2018, 2012). Analyses of fatty acids and sterols profiles are used as identity parameters.

The discrimination, differentiation or classification according to cultivar and/or geographic area has been evaluated for olive oils from Greece (Kosma et al., 2016; Mikrou et al., 2020; Skiada et al., 2020), France (Maléchaux et al., 2019), Turkey (Gumus et al., 2018; Özdikicierler, 2021), Portugal (Rodrigues et al., 2023), Tunisia (Hlima et al., 2017), Italy (Giansante et al., 2003; Sicari et al., 2026), and Spain (Rey-Giménez and Sánchez-Gimeno, 2024).

To date, several studies on Brazilian olive oils have been conducted to evaluate the composition of fatty acids, antioxidant, and volatile compounds. Some of them pointed out possible differences according to cultivars and regions, but the number of samples was always small (Ballus et al., 2015, 2014; Brilhante, 2024; Brilhante et al., 2022; Carvalho et al., 2020; Crizel et al., 2020; Garavaglia et al., 2023; Lima et al., 2023; Rodrigues et al., 2019; Stilo et al., 2023; Zago et al., 2019). No studies with samples from different crops nor with a high number of samples were found. Studies like this are necessary to support improvements in current legislation, since olive oils produced in different countries, regions, and continents have significant differences in their compositions (Arslan et al., 2013; Brilhante et al., 2024, 2022; Garavaglia et al., 2023; Issaoui et al., 2010; Rodrigues et al., 2023).

Thus, the present study aimed to carry out a broad evaluation of extra virgin olive oils produced in Brazil. For this, the identity and quality parameters and the tocopherol composition of 104 Brazilian olive oils from nine cultivars (Arbosana, Arbequina, Coratina, Galega, Frantoio, Grappolo, Koroneiki, Manzanilla, Picual and two blends) produced in the two producing regions of the country (Serra da Mantiqueira and Rio Grande do Sul) were evaluated during four harvests (from 2019 to 2022) to assess the differences in the olive oils from different regions, cultivars, and crops.

2. Material and methods

2.1. Sampling

One hundred and four commercial samples of extra virgin olive oils from four crops (2019–2022), two geographical areas, Rio Grande do Sul (RS) and Serra da Mantiqueira (MA), and from 9 cultivars (Arbosana, Arbequina, Coratina, Galega, Frantoio, Grappolo, Koroneiki, Manzanilla, Picual and two blends) were acquired at local market at the beginning of each crop. Samples, consisting of 500 mL of olive oil from the same production batch, were kept in their original dark green or amber glass bottles, and stored in a freezer (-20 °C) until analysis. The chemical analyses and sensory analysis were performed up to three and six months of storage, respectively. All samples were evaluated and classified by a trained panel as "extra virgin" based on their sensory profile, evaluated according to the standard of the IOC (International Olive Council, 2024). The panel had its competency recognized by IOC for the analysis of olive oils. The evaluation was conducted with, at least, eight trained tasters using an unstructured 10 cm scale, considering positive sensory attributes (fruity, bitter and pungency) and sensory defects (fusty/muddy sediment, musty humid-earthy, winey vinegary, acid-sour, rancid, frostbitten olives, and other negative attributes). The results were calculated as median values per attribute or defect that were higher than zero for fruity attribute and 0.0 for defects.

2.2. Chemicals

The reagents and solvents used for the commercial quality analyses were ethanol 99.5% from Merck (Darmstadt, Germany); phenolphthalein and sodium thiosulfate $\geq$ 99.5% from Spectrum (New Brunswick, USA); potato starch P.A. from Supelco (Bellefonte, USA); spectrophotometric grade cyclohexane and potassium dichromate from Tedia (Fairfield, USA); sodium hydroxide 98.0%, potassium iodide 99.5%, and chloroform 99% all from Sigma-Aldrich (St Louis, USA); and glacial acetic acid 99.8% and fuming hydrochloric acid from JT Baker (Radnor, USA).

For analyses of fatty acids and tocopherols, the reagents and solvents used were potassium hydroxide $\geq$ 85.9% and sulfuric acid $\geq$ 95% from Merck (Darmstadt, Germany); *n*-hexane 99%, ammonium chloride $\geq$ 99.5% and granulated calcium chloride $\geq$ 93% from Sigma-Aldrich (San Louis, USA); methanol, acetonitrile, isopropanol and acetone of HPLC grade from Tedia (Fairfield, USA); HPLC grade hexane from J.T. Backer (Radnor, USA). The gases for chromatography were hydrogen and nitrogen with a minimum purity 99.999%, and synthetic air with a minimum purity of 99.997%.

2.3. Quality parameters evaluated for olive oils

The spectrophotometric examination in the ultraviolet (UV) at 270 nm and 232 nm (K_{270}, K_{232}, and ΔK), free fatty acid content (FFA, expressed as % of oleic acid), and peroxide value analyses were carried out according to the official methods of the IOC (International Olive

Council, 2019, 2017a, 2017b).

2.4. Fatty acid composition

Sample preparation for chromatographic analysis consisted in converting lipids into fatty acid methyl esters (FAME). For the methylation of fatty acids, it was necessary to previously prepare an esterification reagent. In a 500 mL round bottom flask, 240 mL of methanol and 8 g of ammonium chloride were added. To this mixture, 12 mL of concentrated sulfuric acid were added drop by drop. Then the flask was placed in a heater and connected to a condenser and the contents were heated under reflux for 15 min. After cooling, the reagent was identified and stored at room temperature with a shelf life of 12 months (Antoniassi et al., 2018; Hartman and Lago, 1973).

In triplicate, 0.100–0.120 g of olive oil were weighed in 50 mL in the bottom of falcon tubes with screw caps. Then, 1.5 mL of 0.5 N methanolic potassium hydroxide solution was added to the tube, which was closed and placed in a thermostatic bath at 60 °C for 5 min. Afterward, the tubes were shaken three times for 15 s in a vortex, and kept in the bath between agitations. Next, 4.5 mL of the esterification reagent was added. The mixture was placed in the bath at 60 °C for another 5 min, and then shaken twice for 15 s in a vortex, remaining in the bath between the agitations. After that, 10 mL of hexane were added and the tubes were agitated in the vortex twice for 15 s. Then, 10 mL of water was added to the tubes, followed by agitation in the vortex twice for 15 s. Finally, after phase separation, approximately 2 mL of the supernatant (hexane solution) was transferred to a vial for chromatographic analysis. Blank tests were performed for all analyses (Antoniassi et al., 2018). This optimized method performed eight samples with three replicates in four hours.

Gas chromatography was performed in an Agilent model 7890 A gas chromatograph (Wilmington, DE) equipped with a flame ionization detector (GC-FID, sampling rate: 5 Hz) and fitted with a HP FFAP capillary column (stationary phase: nitroterephtalic acid modified polyethylene glycol, 25 m × 0.2 mm × 0.30 μm), with an initial temperature of 150 °C for 1 min. Temperature was then raised from 150 to 180 °C at 30 °C/min; then, from 180 to 200 °C at 20 °C/min; finally, from 200 to 230 °C at 3 °C/min, and kept at 230 °C for 10 min. The running time was 23 min. The injector was kept at 250 °C, and 1.0 μL of a 1% sample solution was injected with a split ratio of 50:1. The detector temperature was kept at 280 °C and the carrier gas (hydrogen) flow was 2.5 mL/min. The identification of the fatty acid methyl esters was carried out by comparing their retention times with GLC reference standards 62, 79 and 87 from NU-CHECK PREP INC™ (Elysian, MN, USA) and with the certified reference material Supelco 37 Component FAME Mix, TraceCERT® CRM47885 (Supelco, Bellefonte, USA).

2.5. Tocopherols

The tocopherols were analyzed in a Waters Alliance 2695 high-performance liquid chromatograph (Milford, Massachusetts, USA) equipped with a quaternary pump system, on-line degasser, column furnace, automatic injection Rheodyne valve (Rohnert Park, USA), connected to Waters 2424 fluorescence detector (excitation at 290 nm and emission at 330 nm). The oil was dissolved in isopropanol (30–50 mg/2 mL). The compounds were separated on a Waters C18 reverse phase column (15 cm × 3.0 mm I.D., 3.5 μm particle size) kept at 35 °C. Samples were kept at 15 °C. The separation was performed using an isocratic flow (0.5 mL/min) with the mobile phase methanol: acetonitrile (1/1, v/v). The total running time was 20 min to allow the cleaning of the column. The identification of the compounds was performed by comparing the sample retention time with those from authentic standards of alpha-tocopherol (T3251, purity ≥96%), gamma-tocopherol (T1782, purity ≥96%) and delta-tocopherol (T2028, purity ≥90%) from Sigma-Aldrich (St Louis, USA). The quantification of the tocopherols was done through external standardization. The concentration of each tocochromanol stock solution was checked after the spectrophotometric reading and using UV absorptivities according to AOCS official method Ce 8–89 (American Oil Chemists' Society, 2017). Calibration curves were prepared on the day of analysis. Examples of curves equations are in the supplementary material, Table S1.

2.6. Statistical analyses

The Chemometric evaluations were performed using XLSTAT software (Lumivero, Denver, CO, USA. Partial Least Squares Discriminant Analysis (PLS-DA) and Principal Component Analysis (PCA) were applied to visualize global clustering and separation trends. After PLS-DA, discriminant analytes with a Variable Importance in Projection (VIP) score greater than 1 were selected for subsequent PCA. Analysis of variance (ANOVA), followed by Tukey's test, was used to assess differences among regions and cultivars and Pearson correlation coefficients were calculated using Statgraphics 6.0 software. For both unsupervised and supervised analyses, all replicates per sample were included. All analyses were carried out in triplicate.

3. Results and discussion

3.1. Identity and quality analyses and tocopherols content

The samples (n = 104) analyzed were composed by the main brands available for sale in the country, from two Brazilian regions (RS and MA), produced from 2019 to 2022. The quality parameters (free fatty acids, peroxide value, K_{232}, K_{270} and Delta K) were all within the regulated values for EVOO (Brasil, 2018, 2012), and are shown in Table 1. There was only one exception that will be discussed below. There were significant differences among samples for all parameters evaluated ($p < 0.05$).

Regarding free fatty acid content (FFA), all the samples had acidity below 0.80%, ranging from 0.10% to 0.71%. In fact, only one sample (Koroneiki – RS) amidst 104 presented FFA higher than 0.6%. This suggests that the fruits used for making the olive oil were in good condition and that measures were taken during harvesting, transportation, storage, and oil production to prevent decomposition by hydrolysis. In this case, the fruits were probably not damaged, as the results are an indication of no fungal growth, and low activity of hydrolytic and/or lipolytic enzymes (Boskou et al., 2006; Brasil, 2018; Mariotti, 2014). All analyzed samples presented a peroxide value below 20 meq O_2/kg, ranging from 2.3 to 16.8 meq O_2/kg, indicating a low concentration of hydroperoxides, which are primary products of oxidation.

The low degree of oxidation was confirmed by the analyses of absorbance in UV. The results of K_{270} were lower than 0.22, except for one Koroneiki sample from Serra da Mantiqueira region (MA) with a value of 0.25, while the results of K_{232} were lower than 2.5, which indicated, respectively a low concentration of unsaturated ketones (products of the auto-oxidation of hydroperoxides) and conjugated dienes (Boskou et al., 2006; Brasil, 2018; Mariotti, 2014). All samples presented Delta K lower than 0.01 (data not shown). The reported limits for quality analysis are similar for both the Brazilian regulation (Brasil, 2012) and the IOC trade standard for olive oils (Codex Alimentarius, 2024; European Commission, 2024, 2022; International Olive Council, 2025).

The fatty acid composition is an important parameter of identity, as it indicates which fatty acids make up the samples and checks whether the product is composed only by olive oil or if it is blended with other oils. Beyond this objective, in this work, the fatty acid composition of EVOOs was also determined to verify whether the olive oil produced in Brazil has a profile consistent with international standards, as soil and climate characteristics influence some identity parameters of olive oils.

As expected, the fatty acid present in the highest concentration was C18:1 (Table 2), comprising oleic (C18:1 *cis*-9) and *cis*-vaccenic (C18:1 cis-11) acids, varying from 63% to 83%. Palmitic (C16:0) ranged from

Table 1
Quality parameters free fatty acids (FFA), peroxide value (PV), and absorbance in UV for Brazilian olive oils produced from 2019 to 2022.

Cultivar	nº of samples	FFA (%)	PV (meq O_2/kg)	K_{232}	K_{270}
Arbosana RS	11	0.15–0.59	4.88–9.54	1.51–1.87	0.09–0.17
Arbosana MA	3	0.15–0.23	6.01–9.7	1.46–1.99	0.13–0.2
Arbequina RS	14	0.11–0.28	3.36–14.61	1.37–2.23	0.1–0.19
Arbequina MA	9	0.08–0.3	5.74–11.84	1.48–1.99	0.1–0.2
Coratina RS	6	0.15–0.31	3.76–6.13	1.46–1.76	0.12–0.21
Coratina MA	2	0.24–0.26	13.25–16.23	1.69–2.05	0.13–0.16
Galega RS	1	0.28	5.85	1.67	0.14
Frantoio RS	5	0.18–0.5	6.18–10.14	1.48–1.86	0.1–0.17
Grappolo MA	5	0.16–0.34	4.98–16.82	1.48–2.08	0.15–0.21
Koroneiki RS	26	0.12–0.72	3.01–13.04	1.22–2.11	0.1–0.18
Koroneiki MA	12	0.18–0.41	4.93–10.36	1.3–1.76	0.09–0.25
Manzanilla RS	2	0.12–0.17	6.02–7.54	1.46–1.7	0.13–0.18
Picual RS	5	0.1–0.25	2.27–6.65	1.14–1.59	0.1–0.15
Picual MA	1	0.14	6.40	1.53	0.20
Blend RS	1	n.a.	n.a.	1.98	0.16
Blend MA	1	0.25	7.39	1.71	0.14
Brazilian Regulation*	-	$\leq$ 0.8	$\leq$ 20	$\leq$ 2.5	$\leq$ 0.22

FFA: Free fatty acids (%, expressed as oleic acid)
PV: Peroxide value
K_{232} and K_{270}: Absorbances in UV at 232 and 270 nm, respectively.
The results are the average of three replicates.
RS: Rio Grande do Sul region
MA: Serra da Mantiqueira region
n.a.: Data not available
*Brasil, 2012.

7.7% to 17.5%, stearic (C18:0) from 1.6% to 2.6%, and linolenic acids (C18:3) from 0.6% to 1.0%. The concentration of *cis*-vaccenic ranged from 1.9% to 4.5% (of the total fatty acids). This range is higher than observed for olive oils of other countries (Scano et al., 1999) and in most publications, the total C18:1 content of olive oil has been reported as oleic acid.

The results observed for minor fatty acids were C17:0 $\leq$ 0.15%, C20:0 $\leq$ 0.49%, C22:0 $\leq$ 0.2%, and C24:0 $\leq$ 0.1%. These data are in compliance with the ranges and limits reported for extra virgin olive oil by the European Commission, the International Olive Council, the Codex Alimentarius and the Brazilian regulation (Brasil, 2018; Codex Alimentarius, 2024; European Commission, 2024, 2022; International Olive Council, 2025).

Additionally, the content observed for C16:1 varied from 0.27% to 2.69%, while the range reported by these regulations is 0.3–3.5%. A single sample of Grappolo from MA region presented a little lower average value of 0.27% but, rounding to one decimal figure (0.3%), also put this sample within the limits.

The differences observed for the 104 samples analyzed and the Brazilian regulation (Brasil, 2018) were related to C17:1 ($\leq$ 0.34%), C18:2 (2.69–12.45%) and C20:1 (0.25–0.51%). Therefore, strictly compared to what is stipulated by the national regulation (Brasil, 2018), not all samples could be classified as "Virgin Olive Oil", type "Extra Virgin/Virgin". Notwithstanding, these results did not indicate adulteration or poor quality, and they should be more accurately considered as characteristic of the Brazilian EVOOs. These "out-of-range" values have been observed in many samples of American and Australian origin (Ceci and Carelli, 2007; Torres et al., 2017). The differences, in comparison to Mediterranean standards, could be related to genotype variations, edaphoclimatic and growing conditions. Such observations led to recent revisions in the international standards (Codex Alimentarius, 2024; European Commission, 2024, 2022; International Olive Council, 2025), setting new limits and ranges for C17:1 ($\leq$ 0.6), C18:2 (2.5–21%), and C20:1 ($\leq$ 0.5%). The Brazilian regulation has not been updated so far. Thus, the results obtained are valuable to establish these identity parameters as characteristics of Brazilian olive oil, providing experimental data to support a revision of the Brazilian regulation by the enforcement agencies.

The lower content of C18:2 (< 3.5%) was observed for one sample of Koroneiki and one sample of Picual from MA region and other sample of Picual from RS region, according to the limit of the Brazilian Regulation (Brasil, 2018), but within the range of international standards (Codex Alimentarius, 2024; European Commission, 2024, 2022; International Olive Council, 2025). Low levels of C18:2 had been previously described for Picual growing in Spain, with an increase in its content during ripening (Beltrán et al., 2004) and showing similar ranges of fatty acids obtained for Brazilian Picual samples. Our results were within the ranges reported for Picual from Argentina (Rondanini et al., 2011), except for C18:2 with average of 7.7%, higher than the range obtained in this study (2.7–5.8%).

Other studies related variations in the fatty acid composition to soil composition, climatic conditions, harvesting techniques, and cultivation practices applied in each region. For C18:1, values ranging from 71.3% to 76.3% for Koroneiki olive oils from various regions from Greece were observed (Kosma et al., 2016; Kotsiou and Tasioula-Margari, 2015; Mikrou et al., 2020), while for the same cultivar in Tunisia the oils presented lower values, around 60% (Dabbou et al., 2009). The fatty acid profile of Koroneiki growing in Brazil is consistent with the ranges observed for EVOO from Greece. Furthermore, differences in fatty acids (C16:0, C16:1, C18:1 and C18:2) were observed for Arbequina cultivated at different growing areas in Spain, Argentina (three different regions) and Australia (Torres et al., 2017). The Brazilian Arbequina EVOO presented a range of C18:1 (63.3–77.6%), larger than the variation observed for EVOO from Spain, which goes from 71.3% to 73.5% (Rey-Giménez and Sánchez-Gimeno, 2024), but higher than the average of 51.8% for Argentinean Arbequina samples (Rondanini et al., 2011). Additionally, the results obtained for the Arbosana, Frantoio, Manzanilla and Coratina were higher for C18:1 and lower for C18:2 when compared to the olive oils of same cultivars from the Northwestern region of Argentina (Rondanini et al., 2011).

The tocopherols contents in Brazilian olive oils (Table 3) are within the ranges observed for other countries, with higher amount of α-tocopherol (136–445 mg/kg), followed by γ-tocopherol (4.6–53 mg/kg), and minor amounts of δ-tocopherol (up to 11 mg/kg). Total tocopherols comprised 148–462 mg/kg. Boskou and collaborators reported total tocopherols of EVOO of different cultivars from Italy, Spain

Table 2
Fatty acid composition (% of total fatty acids) of Brazilian EVOOs produced from 2019 to 2022.

Cultivar	n° of samples	*C16:0*	*C16:1*	*C17:0*	*C17:1*	*C18:0*	*C18:1*	*C18:2*	*C18:3*	*C20:0*	*C20:1*	*C22:0*	*C24:0*
Arbosana RS	11	13.82–17.02	1.53–2.74	0–0.15	0.2–0.34	1.83–2.23	65.04–72.75	6.66–10.78	0.8–0.96	0.39–0.45	0.29–0.37	0.15–0.19	0.08–0.09
Arbosana MA	3	10.92–13.35	1.07–1.66	0.08–0.1	0.21–0.26	1.75–1.92	72.48–78.97	4.11–6.73	0.7–0.83	0.38–0.42	0.34–0.42	0.13–0.19	0–0
Arbequina RS	14	14.54–17.51	1.23–2.72	0.08–0.15	0.19–0.3	1.59–2.09	63.2–71.46	7.93–12.45	0.61–0.83	0.37–0.44	0.29–0.36	0.11–0.15	0–0
Arbequina MA	9	11.14–12.84	0.88–1.56	0.07–0.13	0.17–0.31	1.58–1.87	74.45–77.66	5.59–6.84	0.62–0.94	0.36–0.41	0.35–0.43	0.13–0.17	0.08–0.09
Coratina RS	6	12.07–14.71	0.56–0.92	0–0.06	0–0.11	1.76–2.2	70.11–74.7	7.09–9.6	0.75–1.01	0.37–0.47	0.41–0.5	0.11–0.14	0.07–0.09
Coratina MA	2	11.41–12.22	0.61–1.12	0–0.08	0.13–0.18	1.75–2.6	74.97–75.43	7.1–7.34	0.59–0.82	0.39–0.43	0.28–0.43	0.14–0.15	0–0
Galega RS	1	15.16	1.39	<0.10	<0.10	2.53	68.78	9.55	0.83	0.37	0.25	0.11	<0.10
Frantoio RS	5	13.34–16.1	1.05–1.41	0–0.04	0.08–0.11	1.74–2.3	67.8–74.87	6.43–10.19	0.67–0.77	0.35–0.4	0.29–0.35	0.11–0.12	0–0
Grappolo MA	5	7.68–11.79	0.27–1.02	0–0.08	0.08–0.19	1.7–1.95	74.51 – 83.0	4.28–7.84	0.79–0.9	0.31–0.4	0.41–0.51	0.11–0.15	0–0
Koroneiki RS	26	11.23–14.24	0.68–1.31	0.04–0.06	0.07–0.2	2.1–2.56	73.11–77.77	4.34–6.41	0.72–0.92	0.05–0.49	0.32–0.38	0.12–0.23	0.06–0.08
Koroneiki MA	12	9.73–11.86	0.61–1.09	0.04–0.05	0.07–0.18	1.87–2.23	76.76–81.35	3.42–5.83	0.63–0.85	0.37–0.45	0.34–0.42	0.14–0.18	0.07–0.08
Manzanilla RS	2	15.11–16.26	1.46–1.75	0.12–0.13	0.22–0.24	2.45–2.56	69.95–72.45	4.34–6.13	0.73–0.81	0.46–0.47	0.29–0.33	0.12–0.15	0–0
Picual RS	5	12.86–14.24	1.19–1.46	0–0.05	0–0.11	2.06–2.34	73.79–76.87	3.23–5.37	0.68–0.85	0.36–0.39	0.27–0.3	0–0.14	0.06–0.08
Picual MA	1	11.41	0.90	<0.10	0.10	2.16	79.79	2.69	0.85	0.38	0.33	0.12	<0.10
Blend RS	1	13.34	1.28	0.08	0.19	2.07	72.44	6.87	0.75	0.41	0.35	0.13	<0.10
Blend MA	1	10.92	0.74	0.05	0.11	1.58	78.83	5.20	0.82	0.32	0.43	0.11	<0.10
Brazilian Regulation*	-	7.5–20.0	0.3–3.5	≤0.3	≤0.3	0.5–5.0	55.0–83.0	3.5–21.0	≤1.0	≤0.6	≤0.4	≤0.2	≤0.2

RS: Rio Grande do Sul region
MA: Serra Mantiqueira region
*Brasil, 2012
The results are the average of three replicates.
Limit of detection = ≤ 0.01% and Limit of Quantification = 0.04% (g FAME/ total FAME).

and Greek varying from 55 to 365 mg/kg, and low amounts of β-tocopherol and δ-tocopherol and γ-tocopherol, around 10–20 mg/kg (Boskou et al., 2006). Regarding, EVOO from South America, contents of α-tocopherol (160–428 mg/kg), β-tocopherol (0–27 mg/kg), and γ-tocopherol (0–39 mg/kg) were reported for Argentinean EVOO, with Coratina showing the highest total tocopherols content (Ceci and Carelli, 2007).

There are few published results on tocopherols in olive oils produced in Brazil. For samples of the cultivars Arbequina, Coratina, Frantoio, and Koroneiki also produced in southern Brazil in 2013 and 2014, the α-tocopherol results ranged from 181 to 410 mg/kg (Bruscatto et al., 2017). Variation in the total tocopherols content for the 2017 and 2018 crops in oils from the RS region were recorded. Oil from Arbosana cultivar presented 254 and 325 mg/kg (2017 and 2018 crops, respectively), higher values than those found for Arbequina, Coratina, Frantoio, Picual, and Koroneiki, which varied from 117 to 225 mg/kg (Crizel et al., 2020). The results of the present work, arranged according the production area (Table 3), are within the range of these previous studies. Lower contents of α-tocopherol (29–137 mg/kg) were recorded for 17 samples from MA region (Ballus et al., 2014), but in this case the authors carried out the extraction on a laboratory (not industrial) scale, using an Abencor system.

3.2. *Influence of cultivars, production region, and crops on the identity and quality parameters*

Analysis of variance and correlation for the main identity and quality parameters and tocopherols evaluated in Brazilian EVOOs were performed to understand the influence of cultivars, production regions, and crops, as well as the interactions between these parameters on the results found in the present study. The ANOVA results showed clearly the discrimination by region and cultivar and tendency through the crops. The averages obtained for the two regions, four crops and cultivars, excluding Galega, Manzanilla and blended samples are presented in Tables 4 and 5.

There were significant differences ($p < 0.05$) between the samples amidst the two regions (Table 4). Oils from Serra da Mantiqueira (MA) were higher in C18:1, peroxide value, K_{232} and K_{270}, while those from the Rio Grande do Sul (RS) region presented higher results for C16:0, C16:1, C18:0, C18:2, C18:3, γ-tocopherol, α-tocopherol and total tocopherols ($p < 0.05$). No significant difference was observed for free fatty acids ($p > 0.05$). Considering the quality factors (K_{232} and K_{270}, peroxide value), there were significant differences between regions ($p < 0.05$), and a trend towards better processing conditions was observed for the RS region.

The saturated fatty acid present in the highest concentration was palmitic (C16:0), which also was different between the regions. While olive oils from RS presented a mean of 14.30%, those from MA presented a lower mean of 11.53% ($p < 0.05$). The same difference in fatty acid composition was observed in another study on Brazilian olive oils with the Koroneiki cultivar from the 2018 crop (Brilhante et al., 2022).

Costa and collaborators evaluated nineteen EVOO samples (Arbequina, Arbosana, Koroneiki, and blends) from the MA and RS regions and reported higher contents of C16:0, C16:1, and C18:1 in RS samples (Costa et al., 2020). In the present study, a wide variation in fatty acid composition was also observed; however, the concentration of C18:1 was higher in samples from the Mantiqueira region (76.99%).

In another study, with 22 samples from MA and RS regions from different cultivars (Koroneiki, Arbequina, Arbosana, and blends), higher contents of palmitic acid (C16:0) and lower contents of oleic acid (C18:1) were found in EVOOs from RS. The opposite was observed in EVOOs from Mantiqueira region, which contained higher amounts of C18:1 and lower amounts of C16:0 (Garavaglia et al., 2023), in accordance with the data presented here. This difference in fatty acids composition can be associated to climate conditions, especially with the altitude in which olives were cultivated. MA region is located at

Table 3
Tocopherol content (in mg/kg) in Brazilian EVOOs produced from 2019 to 2022.

Cultivar	nº of samples	α-Tocopherol	γ-Tocopherol	δ-Tocopherol	Total Tocopherols
Arbosana RS	11	268.35–444.92	11.27–18.37	0.61–2.58	287.43–462.03
Arbosana MA	3	233.46–312.91	8.65–18.96	0.62–7.26	248.25–335.62
Arbequina RS	14	241.64–354.32	4.73–14.87	2.41–6.68	252.07–365.23
Arbequina MA	9	187.87–292.7	4.57–25.52	0.76–4.42	194.81–308.91
Coratina RS	6	232.1–361.2	36.55–75.18	2.3–5.62	270.95–428.79
Coratina MA	2	185.81–227.26	15.04–18.46	0.91–4.14	208.2–244.2
Galega RS	1	263.89	22.03	2.32	288.24
Frantoio RS	5	187.2–307.53	14.86–22.88	1.96–11.61	205.45–332.77
Grappolo MA	5	136.36–200.37	9.38–19.24	0–3.76	148.63–223.37
Koroneiki RS	26	219.22–393.29	14.67–35.79	0–12.06	241.14–416.94
Koroneiki MA	12	147.89–302.34	10.08–26.58	1.09–8.58	173.46–323
Manzanilla RS	2	231.92–240.76	40.51–53.63	1.62–4.05	282.5–290.59
Picual RS	5	222.82–279.98	19.69–37.81	1.63–4.1	251.44–312.67
Picual MA	1	154.12	29.01	5.46	188.59
Blend RS	1	365.84	31.26	7.36	404.46
Blend MA	1	171.48	17.55	< 0.10	189.04

RS: Rio Grande do Sul region
MA: Serra da Mantiqueira region
The results are the average of three replicates.
Limit of detection = ≤ 0.1 mg/kg and Limit of Quantification = 0.6 mg of tocol/kg of olive oil.

Table 4
Results of average by region and year of production for quality parameters, main fatty acids (%) and tocopherols content (mg/kg) produced from 2019 to 2022 by ANOVA.

Parameter	Average by region		Average by year of production			
	MA	RS	2019	2020	2021	2022
FFA (%)	0.22^{a}	0.23^{a}	0.28^{a}	0.22^{b}	0.24^{b}	0.20^{b}
PV (meq O_2/kg)	8.86^{a}	6.66^{b}	8.77^{a}	8.13^{ab}	7.39^{b}	5.84^{c}
K_{232}	1.65^{a}	1.59^{b}	1.65^{a}	1.705^{a}	1.574^{b}	1.529^{b}
K_{270}	0.15^{a}	0.13^{b}	0.16^{a}	0.16^{a}	0.13^{b}	0.13^{b}
C16:0	11.53^{b}	14.30^{a}	11.91^{d}	12.80^{c}	13.67^{b}	14.28^{a}
C16:1	0.99^{b}	1.34^{a}	0.97^{c}	1.23^{b}	1.34^{a}	1.15^{b}
C18:0	1.91^{b}	2.16^{a}	2.04^{b}	2.02^{b}	2.03^{b}	2.09^{a}
C18:1	76.99^{a}	71.90^{b}	76.91^{a}	74.69^{b}	72.89^{c}	71.81^{d}
C18:2	5.55^{b}	7.34^{a}	5.09^{c}	6.26^{b}	7.17^{a}	7.48^{a}
C18:3	0.78^{b}	0.79^{a}	0.78^{a}	0.78^{a}	0.78^{a}	0.79^{a}
γ-Tocopherol	14.80^{b}	20.97^{a}	24.41^{a}	14.99^{c}	19.67^{b}	19.42^{b}
α-Tocopherol	224.32^{b}	290.53^{a}	235.3^{b}	274.99^{a}	271.44^{a}	271.08^{a}
Total tocopherols	241.85^{b}	315.03^{a}	263.49^{b}	292.97^{a}	294.43^{a}	293.75^{a}

RS: Rio Grande do Sul region
MA: Serra da Mantiqueira region
FFA: Free fatty acid (%, expressed as oleic acid)
PV: Peroxide value
K_{232} and K_{270}: Absorbances in UV at 232 and 270 nm, respectively.

Table 5
Results of average by cultivar for quality parameters, main fatty acids (%) and tocopherols content (mg/kg) produced from 2019 to 2022 by ANOVA.

Parameters	Cultivars							Interaction (p-value)		
	Arbosana	Arbequina	Coratina	Frantoio	Grappolo	Koroneiki	Picual	Region x year	Region x cultivar	Cultivar x year
FFA (%)	0.24^{abc}	0.17^{d}	0.23^{bcd}	0.30^{a}	0.27^{ab}	0.25^{ab}	0.18^{cd}	ns	ns	ns
PV (meq O_2/kg)	7.40^{bc}	8.27^{b}	7.93^{bc}	7.66^{bc}	10.63^{a}	6.68^{b}	5.08^{c}	ns	ns	$p < 0.05$
K_{232}	1.662^{ab}	1.705^{ab}	1.621^{bc}	1.633^{abc}	1.742^{a}	1.536^{cd}	1.431^{d}	ns	ns	$p < 0.05$
K_{270}	0.138^{b}	0.133^{b}	0.132^{b}	0.128^{b}	0.185^{a}	0.144^{b}	0.131^{b}	ns	ns	$p < 0.05$
C16:0	14.32^{a}	14.74^{a}	13.52^{bc}	14.11^{ab}	9.87^{e}	12.45^{d}	13.42^{c}	ns	ns	ns
C16:1	1.64^{a}	1.69^{a}	0.97^{c}	1.24^{b}	0.68^{d}	0.89^{c}	1.24^{b}	ns	$p < 0.05$	$p < 0.05$
C18:0	1.97^{c}	1.78^{d}	2.04^{bc}	2.06^{b}	1.78^{d}	2.24^{a}	2.19^{a}	$p < 0.05$	ns	$p < 0.05$
C18:1	71.46^{c}	69.97^{d}	72.31^{c}	71.91^{c}	79.46^{a}	76.11^{b}	75.67^{b}	ns	$p < 0.05$	$p < 0.05$
C18:2	7.46^{c}	8.86^{a}	8.21^{ab}	7.98^{bc}	5.21^{d}	5.25^{d}	4.41^{d}	ns	$p < 0.05$	$p < 0.05$
C18:3	0.82^{ab}	0.74^{c}	0.81^{b}	0.74^{c}	0.87^{a}	0.79^{bc}	0.79^{bc}	$p < 0.05$	$p < 0.05$	$p < 0.05$
γ-Tocopherol	15.19^{de}	8.49^{f}	36.77^{a}	20.28^{cd}	13.91^{e}	21.84^{c}	28.20^{b}	$p < 0.05$	ns	$p < 0.05$
α-Tocopherol	314.43^{a}	268.09^{b}	264.33^{bc}	235.22^{d}	173.73^{e}	271.25^{b}	241.98^{cd}	$p < 0.05$	ns	$p < 0.05$
Total tocopherols	331.87^{a}	280.14^{bcd}	304.45^{b}	259.88^{d}	189.93^{e}	296.54^{bc}	273.46^{cd}	$p < 0.05$	ns	$p < 0.05$

altitudes from 1500 to 3000 m while some regions of RS are at sea level. Higher amounts of saturated fatty acids in EVOOs produced at lower

altitudes and higher levels of oleic acid for those produced at higher altitudes have been previously reported for olive oils produced in Turkey and Tunisia (Arslan et al., 2013; Issaoui et al., 2010).

Considering crop years, there were significant differences among crops from 2019 to 2022 for all parameters evaluated (Table 4). It was noteworthy the reduction ($p < 0.05$) of free acidity, peroxide value, ultraviolet absorbency (K_{232} and K_{270}) indicating an improvement in the handling of olives during the harvest, post-harvest, and processing stages. There was a simultaneous reduction of C18:1 and increase of C16:0, C16:1 and C18:2 ($p < 0.05$) from 2019 to 2022. Additionally, there was an increase of α-tocopherol and total tocopherols content ($p < 0.05$).

Comparing the quality and identity parameters of different cultivars (Table 5), significant differences ($p < 0.05$) were observed for fatty acid composition as well for tocopherols. The lower content of C18:2 was observed for Picual, Koroneiki and Grappolo ($p < 0.05$), while Arbequina cultivar has higher amounts of C16:0. C16:1, and C18:2. Koroneiki cultivar presented higher contents of C18:0, C18:1, and C18:3. Koroneiki and Arbequina are the main cultivars growing in Brazil. Other studies with Brazilian olive oils found similar results (Averbuch et al., 2023; Carvalho et al., 2020; Lima et al., 2023). Oil from Grappolo cultivar presented the highest content in C18:1, higher peroxide value, K_{232} and K_{270}, but the lowest content of alpha and total tocopherols ($p < 0.05$). The highest total tocopherol content was found for Arbosana ($p < 0.05$) samples. According to Pérez et al. (2019), the content of tocopherols is highly dependent on the cultivar (genotype), but in a lesser extent, on the crop year climate and the stage of fruit ripening, usually decreasing during the ripening process (Beltrán et al., 2010).

No interaction was observed for free acidity and C16:0, while the other parameters present different behavior and there were more interactions for cultivar x year than for region x year and region x cultivar. The significant interactions for fatty acids pointed out the importance of these parameters for discrimination among regions.

The correlation analysis (Pearson) was carried out for all samples, including all the monovarietal EVOOs and blends (Table S2, supplementary material). Negative correlations ($p < 0.01$) were observed among C18:1 and the most of the fatty acids (C16:0, C16:1, C18:0, and C18:2). Thus, the increase of C18:1 resulted in the reduction of those fatty acids. Similar results were observed previously for Brazilian extra virgin olive oils (Brilhante et al., 2022). These results were consistent with the averages of the regions (Table 4), as MA region showed higher amount of C18:1 and lower results for all the other fatty acids. The C16:0 presented positive correlation with C16:1 and C18:2 ($p < 0.01$) while C18:0 showed positive correlation with C18:1 ($p < 0.01$) and negative correlation with C16:1 and C18:2 ($p < 0.01$). The C18:3 fatty acid presented correlation only with C16:1 (negative, $p < 0.01$).

Concerning tocopherols and fatty acids, negative correlation ($p < 0.01$) was observed for alpha and total tocopherols with C18:1, but positive correlation with C16:0, C16:1, C18:0, C18:2 and C18:3 ($p < 0.01$). These results were coherent with the higher levels of tocopherols and lower results ($p < 0.05$) for C18:1 in the RS region.

Regarding the effect of composition (fatty acids and tocopherols) on the quality parameters, there was positive correlation for C18:0 only with FFA ($p < 0.01$), while negative correlation ($p < 0.01$) was observed between peroxide value and C18:0 and tocopherols (alpha, gamma, and total), as well as for C16:0 ($p < 0.05$). Therefore, the increase in tocopherols content promoted the reduction in the peroxide value, while no effect was observed for the mono and polyunsaturated fatty acids. Negative correlations ($p < 0.01$) were observed amidst alpha, gamma and total tocopherols with the peroxide value, indicating that these components may prevent EVOO oxidation (Lourinho, 2024). In relation to K_{232} value, there were negative correlation ($p < 0.01$) with γ-tocopherol, C18:0 and C18:1, and positive correlation with C16:0 and C18:2 ($p < 0.01$). K_{232} is related to conjugated dienes resulting from oxidation of C18:2. For K_{270}, negative correlation ($p < 0.01$) was recorded with C16:0, C16:1, C18:2, and positive correlation with γ-tocopherol ($p < 0.05$), C18:1 and C18:3 ($p < 0.01$). K_{270} is a parameter related to the presence of conjugated trienes and unsaturated ketones from fatty acids oxidation, and higher amount of these volatiles are expected, as these compounds are produced from C18:3 through the lipoxigenase (LOX) pathway. There was positive correlation among K_{232}, K_{270} and peroxide value ($p < 0.01$), which is related to the oxidation products. The acidity, a measurement of enzymatic hydrolysis, is correlated only with the peroxide value ($p < 0.05$). An increase in acidity is related to poor quality of the olives, a delay in processing after harvesting, malaxation conditions (high time and temperature), which promote hydrolysis as well as oxidation of the fatty acids. The multivariate analysis (see ahead) proved to be useful to discriminate samples and variables.

3.3. *Differences between olive oils produced in distinct regions and from different cultivars*

The data of the main fatty acids and quality parameters were evaluated through principal component analysis (PCA) to provide further information about the pattern of similarity of the observations (samples), regions, and cultivars. It was observed (Fig. 1) that the samples could be grouped by geographic regions (RS and MA). The variables that most contributed to these distinctions were fatty acids, α-tocopherol, and the peroxide value. Strong negative correlations among C18:1 and C18:2, as well as C16:0 and C16:1 were observed, and also between tocopherols and peroxide value, in accordance with Pearson correlation. Furthermore, this strong negative correlation among peroxide value, alpha-tocopherol and some components of phenolic fraction had also been observed on the differentiation of Calabrian EVOO (Sicari et al., 2026). Chemometric analysis and Pearson correlation applied to olive oils from two Brazilian regions (18 samples, two harvests) showed a negative correlation between α-tocopherol and peroxide value, and no effect of the components of the phenolic fraction was observed (Lourinho, 2024). These results pointed out the effect of tocopherols in protecting olive oil from oxidation.

The analytical approaches and the markers employed for discrimination of EVOO according to cultivar and geographic regions vary greatly. Fatty acids and sterols were used as markers (Özdikicierler, 2021; Skiada et al., 2020), as well as fatty acids and squalene (Maléchaux et al., 2019), and quality parameters, fatty acids, tocopherols, hydroxytyrosol, tyrosol derivatives, and oxidative stability (Rodrigues et al., 2023). Rey-Giménez and Sánchez-Gimeno (2024) focused on quality parameters, fatty acids, and sterols. Giansante et al. (2003) selected linoleic acid, C26 alcohol, and stearic acid as the most relevant markers. Mikrou et al. (2020) used fatty acids, tocopherols, and squalene and selected fatty acids as the most important for discrimination. According to Gumus et al. (2018) sterols and fatty acids proved to be an effective tool to cluster the olive oil from different regions whereas triacyclglycerols (TAG) compositional data does not have significant discriminating power. Additionally, a comprehensive analysis was conducted with multivariate statistical tools and total phenolic compounds, α-tocopherol, DPPH radical scavenging activity, acidity, and peroxide value were the key factors in the differentiation among EVOO samples from the three Calabrian cultivars (Sicari et al., 2026).

The analysis of volatile compounds in olive oil has been extensively studied for discrimination among cultivars and/or geographic origin. For this purpose, the analysis is performed by GC-FID, GC-MS, and GCxGC. However, many studies were focused on identification, and some in semi-quantitative results (Brilhante et al., 2024, Stilo et al., 2023). Kosma et al. (2016) based their analysis on volatile compounds and fatty acid composition and concluded that fatty acids proved to be a more powerful tool for differentiation.

The analysis of phenolics has been evaluated for the same purpose, but the results are contradictory, as there are studies that used total phenolic compounds (Folin Ciocalteu) while others used analyses by HPLC-PDA/MS, focusing in different compounds from study to study.

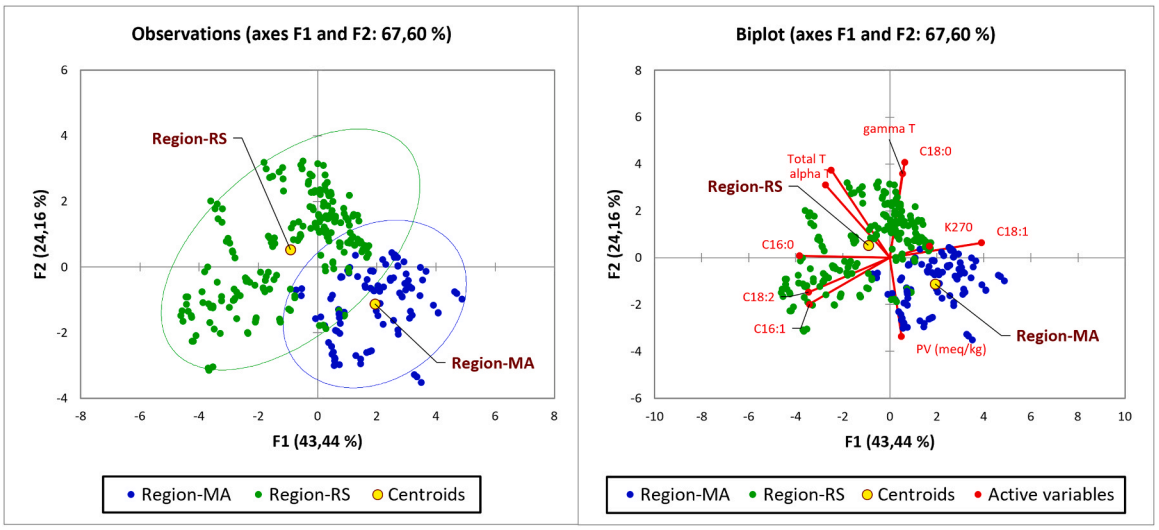

Fig. 1. Differentiation of the samples from RS and MA regions using multivariate analysis.

Hlima et al. (2017) reported fatty acid content as the most informative in discriminating olive oils from production sites than phenolic acids profiles.

The fatty acid profile is useful as a marker for discrimination and for authentication of olive oil, as well as the quality analysis that are necessary to allow the classification of olive oil as EVOO and in the

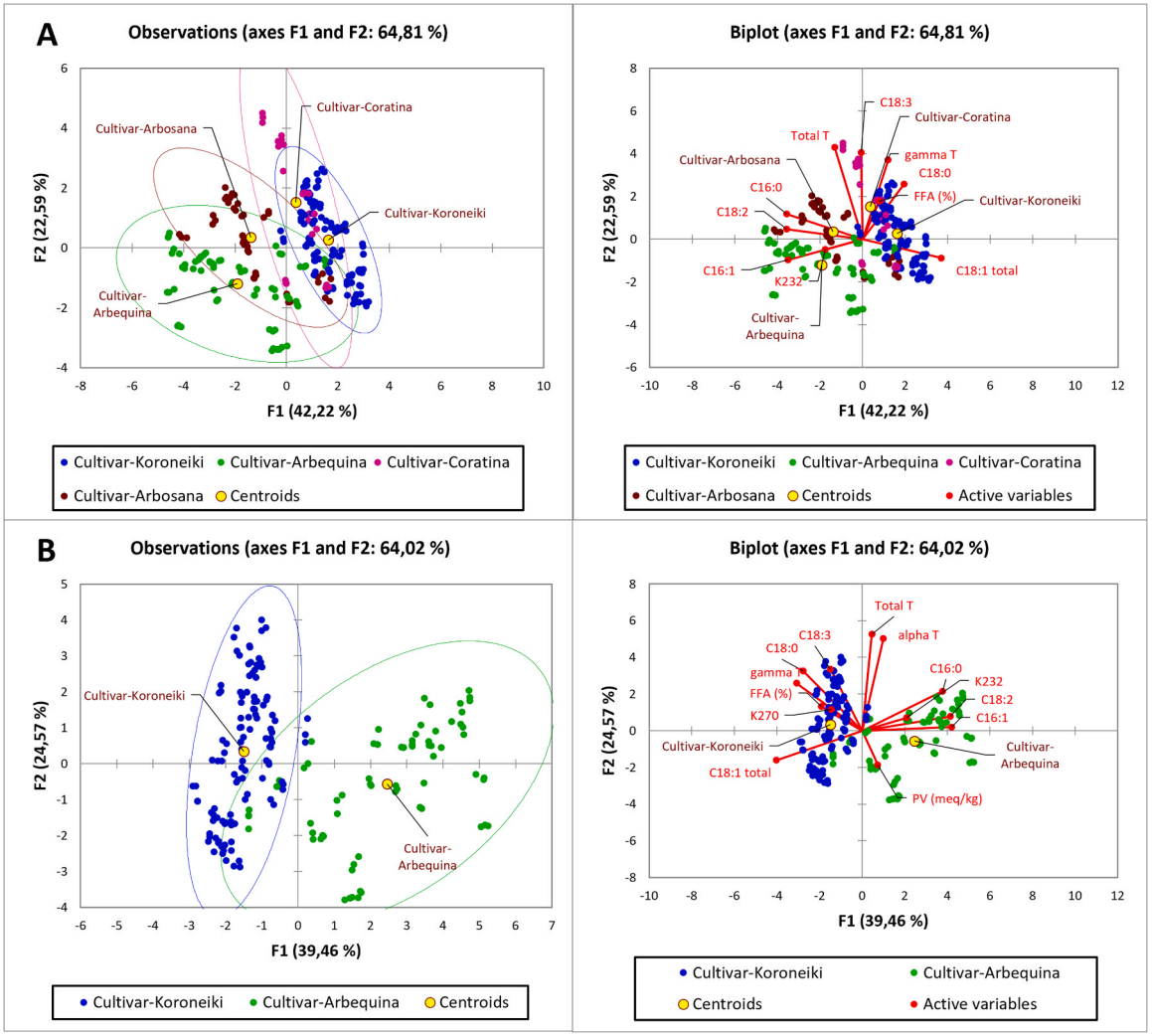

Fig. 2. (2A) Differentiation of the Koroneiki, Coratina, Arbosana, and Arbequina cultivars using multivariate analysis and (2A) Differentiation of the Koroneiki and Arbequina cultivars using multivariate analysis.

comparison among samples, from different producers and provenances. The tocopherols were selected because the analysis by liquid chromatography with fluorescence detector is sensitive and selective for these compounds, and very simple and fast, whereas the phenolic analysis is time consuming. Tocopherols contents are useful due to the activity as vitamin E (Pérez et al., 2019).

Regarding the separation of samples according to cultivar, it was not possible to perform the analysis using all cultivars, as some of them did not have sufficient samples for this purpose. For the PLS-DA followed by PCA analyses, the cultivars Koroneiki, Arbequina, Coratina, and Arbosana were considered, as shown in Fig. 2A. Samples could not be completely separated by cultivar, but it was possible to observe that samples of Arbequina and Arbosana had similar characteristics to each other, as did the cultivars Koroneiki and Coratina.

Considering that the most produced cultivars in the country are Koroneiki and Arbequina, these two were then evaluated separately as shown in Fig. 2B. After PLS-DA followed by PCA, it was verified that samples could be grouped by cultivar (Arbequina and Koroneiki). As reported in other studies, samples from the Koroneiki cultivar could be discriminated by their higher amount of C18:1, while the EVOOs produced from the Arbequina cultivar were characterized by their higher amount of C18:2 (Anastasopoulos et al., 2011; Averbuch et al., 2023; Carvalho et al., 2020; Dabbou et al., 2011; Lima et al., 2023). C18:0 and C18:3 were also important in discriminating samples of the Koroneiki cultivar, while the fatty acids C16:1 and C18:2 were important in discriminating samples of the Arbequina cultivar.

The discrimination observed for regions and cultivars through ANOVA and PCA was attributed to the edaphoclimatic conditions of the two regions evaluated. The climate in the Serra da Mantiqueira region is predominantly humid subtropical with dry winter and temperate or hot summer (Cwb and Cwa, respectively, according to Kopper classification). The average temperature is 21 °C, with average minima of 17 °C and maxima of 27 °C, and accumulated annual precipitation of 1550–1650 mm (Reboita et al., 2015). In Rio Grande do Sul, the other production area, the predominant climate is humid subtropical (or Cfa, in Kopper classification), with average annual temperatures 17.1–20 °C, minima varying from 11 to 15 °C and maxima from 22 to 27 °C (Wrege et al., 2012). The most remarkable difference between regions, however, is their altitudes: Those from RS vary from 9 to 444 m. Altitudes from Serra da Mantiqueira are much higher, all above 900 m, with some farms above 1800 m. According to Bortoluzzi et al. (2026), olive trees may grow from sea level up to high altitudes of 3000 m. However, extreme altitudes are unusual. Regarding tocopherols and C18:1, the results presented here were consistent with the findings for Galega cultivar from seven Portuguese regions, showing negative correlation and positive correlation of altitude, respectively, for α-tocopherol and C18:1 (Rodrigues et al., 2023). Olive oil samples from centenarian trees of eight sites in Portugal at different altitudes were evaluated and a higher content of α-tocopherol for samples of lower altitudes was observed (<150 m). Altitude is probably the factor that most contributed to distinguish between regions in Brazil.

Although the edaphoclimatic conditions in Brazil are different of Mediterranean region, there are consensus that both regions of the country are favorable for the growing conditions of olive tree.

The search for markers to differentiate olive oils from different cultivars and growing areas is challenging, not only due to differences on farming and environmental conditions (including diseases), but also because there are differences in the maturity index of the olives at the harvest, the processing conditions, and storage (Bortoluzzi et al., 2026; Boskou et al., 2006; Inglese et al., 2010; Lechhab et al., 2022; Malheiro et al., 2015). This is especially true when the samples are commercial, obtained from different producers. In Brazil, however, the olive oil production is quite recent, and there is a certain homogeneity in olive processing. Olives are cropped in the early stages to produce green fruity oils, the extraction equipment is from only two manufacturers and are of similar capacity (Almeida, 2022).

According to Lozano-Castellón et al. (2024) the storage at room temperature was the most important factor, followed by olive maturity and malaxation temperature, while malaxation time had almost no effect on the composition and quality of EVOO from Arbequina. The storage promoted reduction of phenolic compounds and increase of quality parameters. To prevent deterioration of the commercial olive oils, samples were collected just after the production, stored frozen, and analyzed within a maximum of 3 months. This can be observed in the results obtained for the 104 samples, which, with the exception of a single one, did meet the limits for quality analysis. We understand that the results obtained are reliable and can be used to compare the two regions and cultivars.

4. Conclusions

Brazilian olive oils are still a recent product, with a great potential to supply a large internal market. Two producing areas are established, with their own peculiarities regarding soil and climate variables, which affect the secondary metabolism of the olive tree and, therefore, the olive oil quality. Although some previous studies on the composition of Brazilian EVOOs were published recently, the number of samples on these publications was small. The data presented here was collected from 104 samples, from four crop years and nine cultivars and provided a large panorama on the quality and identity standards for the EVOOs produced in Brazil. In general, all parameters analyzed lie within the limits of international standards. Some minor fatty acids were detected at levels exceeding the Brazilian regulation, a finding likely associated with local growing conditions and which should prompt a review of national standards. Samples could be discriminated according their origin (RS x MA), a very useful tool for applications of geographical indication. Regarding cultivar discrimination, it was possible to find markers to differentiate Arbequina from Koroneiki, independent of their geographical origin.

CRediT authorship contribution statement

Julianna S. Viana: Investigation, Formal analysis. **Lourinho Jean M. P.:** Investigation, Formal analysis. **Allan E. Wilhelm:** Investigation, Formal analysis. **Bizzo Humberto Ribeiro:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Investigation, Funding acquisition, Conceptualization. **Adelia F. Faria-Machado:** Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Rosemar Antoniassi:** Writing – review & editing, Writing – original draft, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Nathália S. Brilhante:** Writing – original draft, Investigation, Formal analysis, Data curation.

Ethical statements

Ethical protocol for the sensory tests with olive oil was approved by *Centro de Capacitação Física do Exército / Comitê de Ética em Pesquisa* (Army Physical Training Center / Research Ethics Committee, number CAAE: 23840619.3.0000.9433). The volunteers were adults and signed a consent form with the purpose of the study and certified that they decide to participate and had read the information.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jfca.2026.109041.

Data availability

Data will be made available on request.

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